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Influence of position of thermal energy storage with different effectiveness on the performance of BCHP system

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Abstract

Natural gas-driven Building Cooling Heating and Power (BCHP) system shows high energy efficiency and low emission. Nevertheless non-synchronized and fluctuating thermal and electrical demands lead to part load working conditions of the energy supply devices (prime mover and absorption chiller), resulting in low energy efficiency of the whole system. Integrating Thermal Energy Storage (TES) equipment to BCHP proves to be an effective way to improve the system performance. The location of the TES device in BCHP has a great impact on the performance of the whole system. In this paper, a simplified model of BCHP with TES system composed by a Gas Turbine (GT), an Absorption Chiller (AC) and a TES device of different heat exchange effectiveness is presented. Aiming to minimize primary energy consumption, the performances of BCHP systems with different TES locations (upstream and downstream the AC) are compared and analyzed. The preliminary results indicate that it is better for improving efficiency and reducing installed capacities of energy supply devices, to place TES close to users. Moreover, it is shown that the Relative Energy Saving Ratio (RESR) of BCHP with TES system is influenced by whether the co-generated power is merchantable to the power grids. This work is of great significance in further understanding the energy saving mechanism between TES and BCHP and guiding the design of practical BCHP with TES systems.

keywords: Thermal energy storage; Primary energy consumption; Building cooling heating and power; Fluctuating load; Thermodynamic optimization

1. Introduction

Natural gas-driven building cooling heating and power system is of high energy efficiency, low emission, high energy supply safety and reliability [1]. Nevertheless, some practical BCHP systems do not work efficiently. On the one hand, thermal and electrical demands of users are not synchronized. On the other hand, building loads are fluctuating during one day, resulting in part load working condition, which may lead to low efficiency of the energy supply devices [2]. Many studies investigated on the thermodynamic or economic analysis of BCHP with TES [3, 4], demonstrating it as an effective device to improve the performance of the system [5]. However, seldom researches focused on the system structure

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design, especially the optimization of TES position, even though the location of the TES in BCHP has a great impact on the performance of the whole system. Thus the installation place of the TES device in a system is an important but unsolved problem. In this paper, a simplified model of BCHP with TES system is built. Aiming at saving primary energy consumption, the performances of BCHP systems with different TES locations are compared and analyzed, to deeply investigate and understand the energy saving mechanism between TES and BCHP.

2. System Model

The typical BCHP system is shown in Fig.1. The GT often runs under part load conditions because of the fluctuating load. Eq. (1) gives an explicit analytical solution of part-load performances of constant rotating speed single shaft gas turbine [6]. In this equation, η (%) and P (kW) represent the efficiency and electric power of the GT respectively and subscript e denotes the value in rated condition. This semi-empirical analytical model is widely used in BCHP system simulation.

$$\frac{\eta}{\eta_e} = f(\frac{P}{P_e}) = 2.648\frac{P}{P_e} - 3.587(\frac{P}{P_e})^2 + 2.816(\frac{P}{P_e})^3 - 0.913(\frac{P}{P_e})^4 \tag{1}$$

From the perspective of thermodynamics, an absorption chiller can be regarded as a heat engine and a heat pump, whose performance is highly influenced by generation temperature (T_1), evaporation temperature (T_3) and condensation temperature (T_0). The thermodynamic model is given by Eq. (2), where X is the thermodynamic perfectness of the AC.

$$COP = X\frac{T_1 - T_0}{T_1}\frac{T_3}{T_0 - T_3} \tag{2}$$

When the GT works at full load, T_1 and COP of the AC reach the rated values. Assuming a rated COP of 1.4 for the AC, when T_1=773 K, T_3=280 K, T_0=298 K, a value of 0.146 is obtained for X. It is supposed that X remains constant during temperature changes.

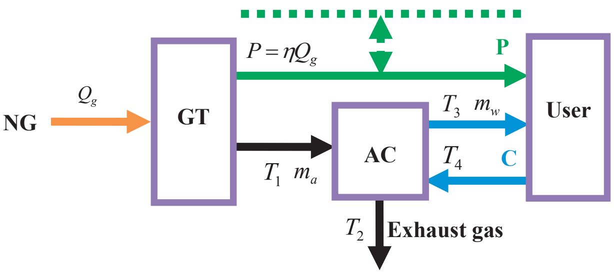


Fig. 1 Schematic diagram of BCHP system in summer

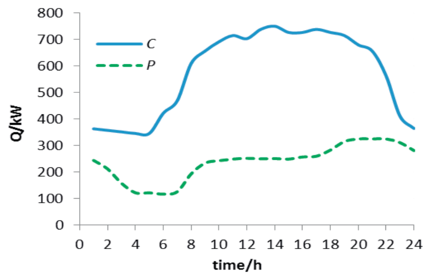


Fig. 2 Cooling and power loads

A TES device can be viewed as a heat exchanger with non-synchronized heat transfer. In Eq. (3), we define the effectiveness of the TES just like a heat exchanger, where $T_{c,i}$, $T_{c,o}$, $T_{d,i}$, $T_{d,o}$ are the working fluids inlet and outlet temperatures during charge and discharge process respectively.

$$\varepsilon = \frac{T_{d,o} - T_{d,i}}{T_{c,i} - T_{d,i}} \tag{3}$$

To simplify the analysis, only ε is used to describe the thermal performance of the TES device. When ε=1, there is no irreversible loss whereas when ε<1, there must exist temperature loss after charge and discharge process. Meanwhile, it is assumed that the energy storage capacity of the TES is infinite and heat energy can be charged and discharged at will, regardless of time.

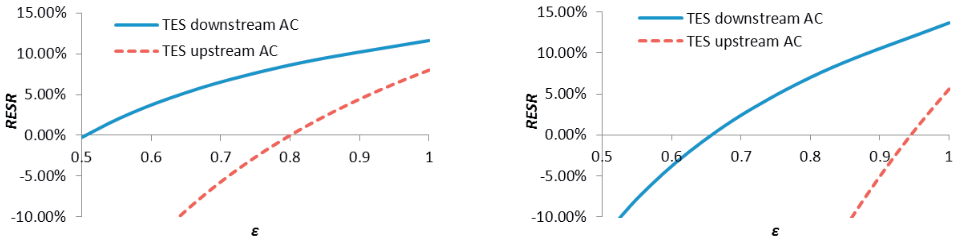
3. Illustrative Example

Fig.2 shows the hourly loads of a 10000 m^2 hotel in Beijing on a typical day in summer. It is known that η_e=35%, T_2=180 K, $c_{p,a}$=1.2 kJ/kgK, T_3=280 K, T_4=285 K. It is assumed that the co-generation system works under following thermal load mode and the lacking power can be purchased from the power grids (η_{grid}=55%). For BCHP system without TES, the installed capacity of GT and AC is determined based on the peak load. Moreover, η of GT and COP of AC are changing with time. To improve the performance under part load condition, a TES device (ε=1) is introduced into the system. If the TES device is placed downstream to the AC in order to store the cooling water at peak time, both GT and AC can work steadily under rated conditions. The TES device can also be placed upstream to the AC in order to store the heat of redundant exhaust gas at peak time. During the discharge process, exhaust gas of GT is mixed with the one flowing out from TES and sent to AC together. As a result, GT works steadily while AC does not. We define Installed Capacity Reduction Ratio (ICRR) of GT and AC, Relative Energy Saving Ratio (RESR) of BCHP with TES to that without TES, to evaluate the effects of TES. The calculation results are shown in Tab.1.

Tab.1 Comparison between BCHP without and with TES of different positions

	Working condition		ICRR (%)		RESR (%)
	GT	AC	GT	AC	
No TES	unsteady	unsteady	-	-	-
TES upstream AC	steady	unsteady	18	0	8
TES downstream AC	steady	steady	23	23	12

The effectiveness of TES device may have a great influence on the performance of the whole system. Fig.3 shows the comparative results of two different TES position in BCHP with different effectiveness's.



(a).Co-generated power is merchantable (b).Co-generated power is unmerchantable

Fig. 3 Variation of RESR with changing ε of TES

It is clear that RESR decreases with decreasing ε and it becomes more sensitive to ε if TES is installed before the AC. If ε=1, RESR reaches the maximum value, just as the situation mentioned in Tab.1. When ε decreases to a certain value, RESR becomes negative. This means the performance of BCHP system with the TES is worse than the one without it. Moreover, if the superfluous co-generated power is un-merchantable to the power grids, the RESR decreases more sharply. So merchantability of co-generated power is good for energy efficiency. The results also indicate that under the same conditions, it is preferable to place the TES device downstream to the AC to save the primary energy. The value of RESR is highly influenced by practical performance of devices (GT, AC and TES) and user loads.

4. Conclusions

The location of the TES device in BCHP has a great impact on the performance of the whole system. In this paper, a simplified model of BCHP with TES is built and the performances of BCHP systems with different TES locations are compared. The preliminary results show that RESR decreases with decreasing ε of TES and it highly depends on whether the co-generated power is merchantable to the power grids. It also indicates that it is better for improving efficiency and reducing installed capacities of energy supply devices to place the TES equipment close to users. This work is of great significance in deeply understanding the energy saving mechanism between TES and BCHP and guiding the design of practical BCHP with TES systems.

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Biography

Yin Zhang is a Ph.D. candidate in the department of building science, Tsinghua University. He got bachelor's degree of engineering in Huazhong University of Science and Technology in 2011. His research interest focuses on building energy efficiency.